

19. *On the INTRUSIVE CHARACTER of the WHIN SILL of NORTHUMBERLAND.* By W. TOPLEY, Esq., F.G.S., Assoc. Inst. C.E., Geological Survey of England and Wales, and G. A. LEBOUR, Esq., F.G.S., Lecturer in Geological Surveying at the University-of-Durham College of Physical Science, Newcastle-on-Tyne. (Read December 6, 1876.)

(Communicated to the Society by permission of the Director-General of the Geological Survey.)

[PLATE XVIII.]

CONTENTS.

1. Introduction.
2. The Carboniferous-Limestone Series of Northumberland.
3. Bibliography.
4. Stratigraphical Relations.
5. Mineral Characters.
6. Age and Origin.
7. Conclusion.

1. *Introduction.*—The basaltic rocks of the north of England occur in two forms—as *sheets* lying amongst the sedimentary strata, and as *dykes* cutting through them. The intrusive character of the latter is, of course, undisputed; but there is much uncertainty in the minds of many geologists as to the character of the former.

In this paper we purpose to show, from the detailed work of the Geological Survey, that in Northumberland there can be no doubt whatever as to the intrusive nature of the bed or beds of basalt known as the Whin Sill. This conclusion can be established both by the evidence of individual sections and by the line of outcrop of the trap.

The question of the nature of the Whin Sill is of importance in three ways:—1st, as a point of theoretical geology, bearing upon the history of volcanic action in Britain; 2nd, in reference to the classification of the Carboniferous System; 3rd, in its bearing upon practical mining.

The Whin Sill is best known in Teesdale, especially in the two fine waterfalls of High Force and Cauldron Snout. It also appears along the face of the Penine escarpment, and is beautifully exposed in the “Nicks” which furrow the face of that range. Although this district is known to us, we will not stay to describe it, because it has already much engaged the attention of geologists, especially Professors Sedgwick and Phillips. It is generally supposed that there is but little evidence of intrusion there; but this is not the case; the evidence is plain if one only looks for it, and it was sufficient to satisfy so close an observer and so clear a reasoner as Professor Sedgwick.

One of the finest sections along the Penine escarpment is that at

High-Cup Nick, about 4 miles east of Appleby. Here the Whin Sill (75 feet thick), and the beds above and below it, are beautifully exposed. The roof and floor of the basaltic sheet consist of shale, both equally baked and altered for several feet from the line of contact with the Whin.

As regards this escarpment, the continuous interbedding of the Whin has been simply assumed; the evidence, when carefully examined, tells the other way. Mr. J. G. Goodchild, F.G.S., of the Geological Survey, has proved that the trap is certainly intrusive here. In a letter to us (dated Jan. 27, 1876) he says that at Renwick the Whin "is found at from 250 to 300 feet below the Four-fathom Limestone. In another part it comes immediately below the Scar Limestone; and as one follows the outcrop [southwards] towards Brough, it is found at successively lower horizons, until near Roman Fell it lies on the top of the Melmerby-Scar Limestone. In other words, between Renwick and Brough [19 miles] the Whin Sill cuts through about 600 feet of the Carboniferous Limestone Series."

Mr. C. T. Clough, of the Geological Survey, has recently shown that even at the typical section of High Force itself the Whin can be shown to be intrusive; and he adds:—"I have very little doubt that the more the country is worked over, the more and more evident will the intrusive character of the Whin Sill become*."

It may be well to mention that the term *Whin* is rather loosely used in the north of England. Basalt is so termed; but the word is also applied to the Porphyrite of the Cheviots and to any unusually hard quartzose sandstone. The hard sandstone is sometimes spoken of as "white" or "grey" whin, whilst the Basalt is called "blue whin." The hard cherty sandstone which occurs in the Lower Greensand of West Sussex is called Whinstone; and the term "whin" is applied to hard sandstone in the South-Wales Coal-field. In Leicestershire it is applied to the remarkable bed of trap which occurs at the south-eastern part of the Coal-field, and also to hard sandstone or chert.

In the lead-mining districts of the north of England the various beds are called "Sills." As the miners have always regarded the basalt as a true bed, it has been called the "Whin Sill." It is also sometimes called the "Great Whin Sill," to distinguish it from the "Little Whin Sill" of Weardale. We believe both of them to be branches of the same intrusive sheet.

2. *The Carboniferous-Limestone Series of Northumberland.*—In order that the following details may be understood, it is desirable to give some account of the succession of beds below the Millstone Grit in Northumberland. It is customary to retain for the north of England the old-established divisions of Coal Measures, Millstone Grit and Carboniferous Limestone. These names were first given in the south-west of England, where well-defined divisions corresponding to them exist. But if the Carboniferous Series had been first

* Quart. Journ. Geol. Soc. vol. xxxii. p. 471, 1876.

studied in Scotland or Northumberland, it is very doubtful whether such divisions would ever have been made in those areas; thick beds of sandstone (often coarse and pebbly), and bands of shale, extend right through the series. In the higher part (the Coal Measures) there are good seams of coal; in the lower part (the Limestone Series) there are bands of limestone and seams of coal; in the middle part (the Millstone Grit) there is no limestone, and rarely any coal.

The term "Yoredale Rocks" was introduced by Professor Phillips to designate a series of beds lying between the "Main" or "Great Limestone," and the "Tyne-Bottom Limestone," succeeded below by the "Scar-Limestone Series." The typical section is that in Upper Wensleydale. The Millstone Grit of this author included all beds between the Great Limestone and the Coal Measures, whether they contained limestones with marine fossils or not. They do include such limestones even in North Yorkshire; in Northumberland there are from three to six well-marked limestones within this distance.

The Whin Sill of Teesdale, Alston, &c. lies just below the Tyne-Bottom Limestone, or is always supposed to do so. If this band of trap occupied a constant horizon, it might serve as a convenient boundary, though it would not necessarily be a natural one. It has generally been assumed that such is the case; and the base of the Yoredales has been drawn accordingly in geological maps.

One important result of recognizing the intrusive character and varying position of the Whin Sill is this, that it is no longer to be relied upon as a boundary*. Not only does it shift about, in places lower, more often higher than the supposed base-line, but it sometimes lies above the Great Limestone itself; that is to say, the bed of trap which is supposed to mark the base of the Yoredale Series sometimes lies above the limestone which forms the top of that series. It is very doubtful whether the so-called "Tyne-Bottom Limestone" of the miners is always the same bed; and certainly this limestone cannot be traced northwards through Northumberland. As in this country there is no definite base for the Yoredales, so there is no reason, supplied by the characters of the rocks, for drawing a line here at all. Professor Phillips himself saw this difficulty; for he says:—"In this progressive change of character to the northward, we lose by degrees the distinction of lower scar limestone; and it becomes not only difficult to draw the line for its upper boundary, but doubtful whether it is proper to make such an attempt. In the northern parts of Northumberland it appears

* For a further discussion of this question see G. A. Lebour "On the Limits of the Yoredale Series in the North of England," *Geol. Mag.* Dec. 2, vol. ii. p. 539, 1875. In this paper the term "Bernician Series" is proposed for the beds lying between the Millstone Grit and the Tuedian Beds or Calciferous Sandstones (the "Valentian Series" of Prof. A. Geikie, MS.). Subsequently to the publication of this paper it was found that the term "Bernician" had been proposed as a division of the Carboniferous Limestone by Dr. S. P. Woodward in 1856; it was adopted by Dr. Karl Mayer in 1874. (See G. A. Lebour, *Geol. Mag.*, Dec. 2, vol. iii. p. 19.)

neither desirable nor possible to separate the lower from the similar middle and upper calcareo-carboniferous groups" *.

In the maps of the Geological Survey, as yet published, all the beds in Northumberland and Durham, below the Millstone Grit, are grouped as the "Carboniferous-Limestone Series." This includes the Yoredales of Phillips and also his Scar-Limestone Series. The lower beds (the Tuedian of Tate, or Calceiferous Sandstone of Maclaren and the Geological Survey of Scotland) are not yet surveyed, and it is as yet uncertain where (in Northumberland) the line must be drawn. The Whin Sill is wholly comprised within the Carboniferous-Limestone (Bernician) Series of Northumberland and Durham; it never approaches beds which any one could suppose to be Tuedian.

3. *Bibliography.*—The Basaltic rocks of the north of England are frequently mentioned by the older geological writers on the district; but the question as to whether the Whin Sill is intrusive or contemporaneous does not seem then to have arisen. The Whin is described as "interstratified" and as occurring in "overlying masses," the latter term apparently referring to areas where the Whin has been exposed by denudation, although the exact sense in which it was used cannot always be determined.

The earliest paper claiming special notice here is one by Mr. (now Sir Walter) Trevelyan, published in 1823 †. A careful account is there given of the geology of part of the northern coasts of Northumberland; a map and section accompany the paper, showing how unevenly and irregularly the Basalt lies amongst the strata in that district. The limestone lying *upon* the Whinstone is described as being very crystalline towards and at the point of contact.

Professor Sedgwick printed in the Cambridge Transactions ‡ two valuable papers upon the Trap rocks of Durham. He showed from a consideration of the Teesdale district, in which the position of the Whin Sill is most constant, that there is abundant evidence of intrusion, the beds below being frequently broken and partially enclosed within the Whin, whilst the beds above are sometimes metamorphosed, this metamorphism of the upper beds being most apparent when the Whin is thickest.

Mr. W. Hutton is the only writer who has described in any detail the general range of the Whin Sill of Northumberland §. He regarded it as strictly contemporaneous; and where two or more distinct beds of Whin are known in one district, he supposed that there had been successive eruptions over the ocean-floor. A paper, probably the same, was read before this Society by Hutton, but was published only in abstract ||. In this abstract the author is repre-

* Geol. of Yorkshire, Mountain-Limestone District, p. 35, 1836.

† Mem. Wernerian Soc. vol. iv. part ii. p. 253. In the following vol. (p. 475, 1826) Mr. Witham describes the basaltic rocks of the north of England, but without throwing any further light on this question.

‡ Vol. ii. pp. 21 and 139, 1827.

§ Trans. Nat.-Hist. Soc. Northumberland &c. vol. ii. p. 187, 1832. (Read Dec. 19, 1831.)

|| Proc. Geol. Soc. vol. i. p. 341, 1832. (Read Dec. 14, 1831, and Jan. 4, 1832.)

sented as accepting Sedgwick's conclusions as to the intrusive character of the Whin Sill in Teesdale; but this must be an error*.

Professor Phillips, giving most weight to the conformable nature of the beds in Teesdale and along the Penine escarpment, considered the Whin Sill to be of contemporaneous date; and he accounted for the altered nature of the overlying beds by supposing that the heat from such thick masses of lava had not time to escape before these beds were deposited. He admits some eruptive force, but apparently only so far as to allow of the Whin reaching the sea-bottom, over which he supposes it to have flowed†.

The late Mr. G. Tate published several papers on the Geology of Northumberland, particularly on the northern part of the county. Frequent mention is made of the Whin Sill, and illustrations of its intrusive character are given. These papers‡ were published in the Transactions of local societies, or in books relating to Northumberland. Had they been published in works generally accessible to geologists, the question in dispute would probably have been settled years ago.

Of other geologists who, from personal knowledge, admit the intrusive nature of the Whin Sill we may name Mr. Howse, Mr. Kirkby, and the whole of the officers of the Geological Survey to whom the district is known§.

Amongst those who, in published papers, regard it as interbedded and contemporaneous are Professor H. A. Nicholson, Mr. Bewick, Mr. J. A. Knipe, and Mr. N. Wood||.

The intrusive nature of the Whin Sill is shown on the Maps and Sections of the Geological Survey¶. In the year 1873 we laid

* The paper read at Newcastle is published in full, and it received additions and corrections by the author before publication. This, therefore, certainly represents Hutton's views correctly; and here he dissents entirely from Sedgwick's conclusions.

† Geology of Yorkshire, part ii. p. 85, 1836. At the Bradford meeting of the British Association, when some of the facts hereafter mentioned were laid before the Geological Section, Professor Phillips admitted that we had proved the intrusive nature of the Whin Sill for the districts described.

‡ The most important paper is that "On the Basaltic Rocks of Northumberland," Proc. Berw. Nat. Club, vol. vi. p. 197. See also papers in vol. iii. pp. 99, 233; Tate's History of Alnwick, vol. ii. p. 461, 1869; and other works.

§ Mr. W. Boyd (Trans. N. Engl. Inst. Eng. vol. ix. p. 185, 1861) described the Whin Sill of the northern part of Northumberland as contemporaneous. He now believes it to be intrusive; Mr. Hedley is also of this opinion.

|| In the paper, as laid before the Society, full reference to all publications on the subject were given. In the discussion which followed the reading of this paper, Mr. W. W. Smyth stated that Mr. Blackwell regarded the Whin Sill as intrusive. We have been unable to find any published opinion by him on the subject.

¶ Sheet 105 N.W. was published in 1871; this map (by the authors of this paper) includes the Whinstone area near Kirkwhelpington. Several sheets of the six-inch map of Northumberland, including parts of the Whin Sill, are published. Sheet 108 of the Horizontal Sections, by Mr. H. H. Howell, was published in 1875; in this the Whin Sill of Great Swinburne is marked as an intrusive sheet.

before the British Association a brief outline of the facts now to be detailed*.

Whilst geologists generally are divided in opinion as to the nature of the Whin Sill, those who are also practical miners are almost unanimous in regarding it as contemporaneous. Doubtless this arises from the fact that in the districts which have been most explored by mining the Whin happens to lie with greatest regularity. But frequently this constancy is assumed without proof; and it is often thought to be proved by reasoning in a circle. The so-called "Little Whin Sill" of Weardale is a case in point. This was always considered to be the "Great Whin Sill;" and therefore the limestone lying on it was called the "Tyne-Bottom Limestone." A miner would have said:—"This is the Tyne-Bottom Limestone; and therefore the Whin is in the usual place." Sir Walter Trevelyan, however, long ago proved this to be mistake, and that the Whin of Weardale lies much higher in the series than the Whin of Alston and Teesdale†.

4. *Stratigraphical Relations of the Whin Sill.*—We have thought it better to select some of the more striking sections which illustrate our views as to the intrusive character of the Whin Sill, than to describe one by one all the sections on which they are based. It must therefore be clearly understood that the evidence here offered represents by no means all that it is in our power to bring forward, but consists of what appears to us to be of sufficient weight to prove our case.

The portion of the Whin Sill to which the accompanying sections (Pl. XVIII.) refer is that which lies between Haltwhistle and Dunstanborough, within which limits it forms an intermittent line of outcrops some 80 miles in length.

In order to give a key to the relative positions of the horizons with which we have to deal, a diagram, to scale, is annexed. To this is added part of Westgarth Forster's well-known "Section of the Strata" in the Alston-Moor district. This section (from the Tyne-Bottom Limestone upwards), it will be seen, does not hold perfectly good throughout the district under our notice, chiefly owing to a considerable increase in thickness in the series in Mid Northumberland.

On entering the county the Whin is for a space lying above the "Great" Limestone, some 700 or 800 feet above its Alston horizon, but returns to its usual Penine position before long, near to which, with fluctuations above and below within about 300 feet, it keeps running at first in an easterly direction, and taking, on nearing the North Tyne, the north-easterly bend to which all the beds of the district are subject. At Low Teppermoor it is seen at about its lowest horizon; and here a short surface break is very well shown. Thence it continues to the N.E. pretty much along the same horizon till it reaches Swinburne Mill, where another surface break occurs accompanied by a rise of a few feet to the next higher bed of lime-

* Brit. Assoc. Rep. for 1873, Trans. Sec. p. 92.

† Trans. Nat.-Hist. Soc. Northumberland &c. vol. i. p. 58, 1831.

stone. From this point the Whin Sill trends almost due north in a fine line of semi-columnar crags as far as Knowes Gate, where it crosses the Wansbeck-Valley Railway. This portion of its course is twice interrupted by surface breaks unattended by change of horizon, at Sweethope and at the Berry Hills. At Knowes Gate this long basaltic range terminates abruptly, reappearing at intervals through a drift-covered country. Parallel to this great ridge, however, and not quite a mile to the east of it (three beds of limestone, with their associated sandstones and shales intervening), is another equally thick (and in places even thicker) but much less regular Whin Sill, which we will call the Eastern Branch, and which runs from Homilton, near Bavington, to Elf Hills, to the N.E. of Kirkwhelpington (see fig. 1). This eastern basaltic sheet is much more subject to breaks than the western one, and towards its northern extremity comes to the surface usually not as a continuous bed, but in bosses or isolated masses of greater or less size.

At Elf-Hills Quarry, where the Four-fathom, or *Saccamina*-Limestone* was until lately wrought, the Whin overlies and breaks through the limestone. But a more interesting case of intrusion was observed by Sir W. Trevelyan a few years back, which is illustrated by fig. 2, from a sketch by us, taken at the time: a thin layer of fine-grained Whin underlies the limestone and sends up strings of trap through the overlying beds.

To the north of Elf Hills there is a broad flat tract of drift-covered land, beyond which the Whin is again seen (at Hartington and Gallow Hill) lying in the same position as the main bed at Elf Hills, between the Great and Four-fathom Limestones. Again there is a broad drift-covered valley, beyond which the Whin is seen at Dike Head. It here seems to come up as a great boss, and lies lower in the series than at Elf Hills. A borehole put down on the south of Greenleighton Farm found the Whin just below the Six-yard Limestone (=Three-yard Limestone of Teesdale).

In Fallowlees Burn the Whin lies about 100 feet below the position last mentioned. From this place it can be traced for about a mile to the north, apparently keeping at the same horizon.

At Wards Hill (fig. 3) the Whin lies *above* the Great Limestone. A little below the Great Limestone there is a seam of coal which has been a good deal worked over the north-eastern part of the hill. At one pit the coal was followed for some distance under the Whin, where it was found to be gradually deteriorating and at last was quite caked and worthless. The Whin has then evidently cut through the limestone and has here reached the coal. This is also evident from the surface-mapping; for on the south-east face of the hill the limestone occurs above the Whin, and on the south-west the Whin certainly cuts through the beds, passing through the Great Limestone and the beds below, and at last underlying the coal, which lies about 40 or 50 feet below the Great Limestone.

The Whin is not seen again until we reach the hill N. of Shield-

* Through Northumberland, as far north as the river Aln, *Saccamina Carteri*, Brady, appears to occur chiefly in the Four-fathom Limestone.

Fig. 1.—Sketch Section across both branches of the Whin Sill, showing their probable mode of connexion near Great Bavington (about 2 miles).

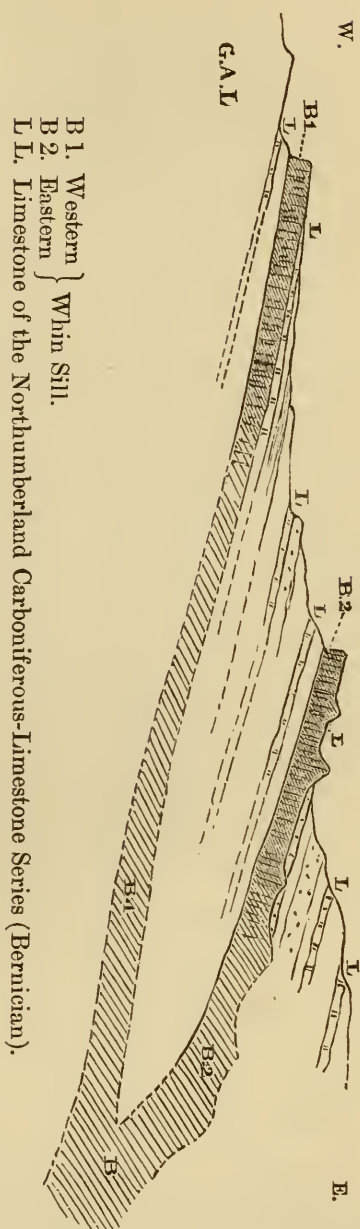
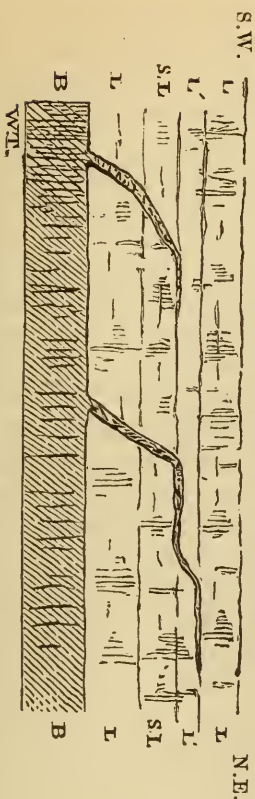
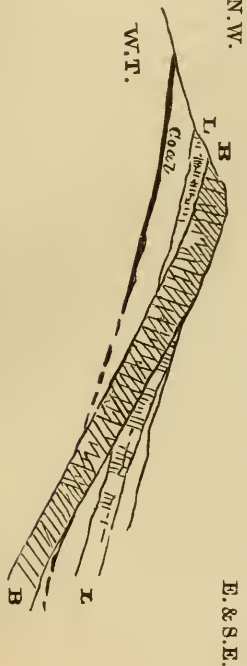


Fig. 2.—Sketch in *Elf-Hills Quarry* (1st August, 1871).



B. Branch of Whin Sill, 3 to 4 ft. thick (exposed at intervals), sending strings of basalt into the Limestone.
 L. Bed of impure limestone.
 S L. *Saccamina*-beds.

Fig. 3.—Sketch Section through *Ward's Hill*.



B. Whin Sill.
 L. Great Limestone.

Dykes Farm, about $4\frac{1}{2}$ miles south of Alnwick. Hence it can be traced northwards, past Rugley, nearly to Alnwick, lying about 100 feet, or rather more, above the Hobberlaw Limestone, which is the lowest good and thick limestone of the series in that district. Here, too, the Whin has its lowest known position, as it lies nearly 1000 feet below the Great Limestone. The beds immediately above the Whin are seen in a stream south-east of St. Margaret's Farm, where they are much altered.

Here we approach the country so well known to the late Mr. G. Tate. The evidences of intrusion here are so abundant, and the Whin has been so well described by Mr. Tate, that we need not repeat the evidence in detail. From Ratcheugh northwards to Dunstanborough the Whin lies in beds and bosses at various horizons, but chiefly about the Great, Eight-yard, and Six-yard Limestones.

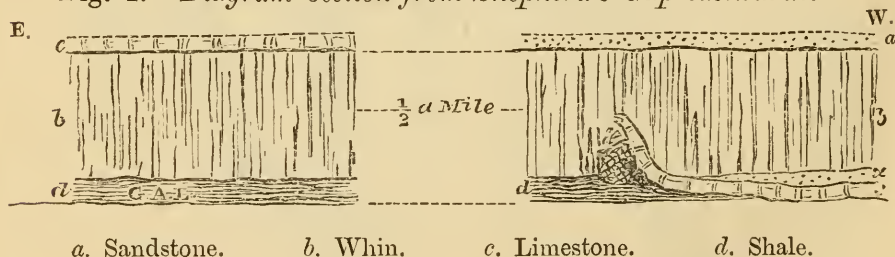
At first one is disposed to believe that the Whin here lies more irregularly than really is the case. But there are a great number of faults separating the beds. Still there can be no question as to the fact that the Whin breaks through the beds, and also that it alters the rocks above it quite as much as it alters those below.

The northern part of the county has been described by Sir W. C. Trevelyan in the early paper already referred to. In Mr. Boyd's paper many stratigraphical details are given, from which it appears that the Whin west of Holy Island lies some 800 feet above the Great Limestone, quite in the top beds of the Carboniferous-Limestone series. In this district the Woodend Limestone (or the Hobberlaw Limestone) lies about 1000 feet below the Great Limestone.

Now, on the south of Alnwick, near Rugley, the Whin lies about 100 feet above the Hobberlaw Limestone; so that comparing the two districts, we find that the Whin lies about 1700 feet higher in the series near Holy Island than it does just south of Alnwick.

At very numerous places along the outcrop of the Whin Sill minor but equally good evidence of its non-contemporaneity is forthcoming. Among these the section at Shepherd's Gap (fig. 4) along

Fig. 4.—*Diagram Section from Shepherd's Gap eastwards.*



The Limestone seen lying upon the Whin in the eastern portion of the Section is the same as the one shown lying beneath it in the western portion, and being thrust into it. The beds lying above the Whin Sill are seen on the dip-slope of the basaltic sheet at a lower level than the top of the escarpment; it has therefore been necessary to bring them out of their proper plane in order to show them in the sketch. Although the upturned limestone is very clearly shown in the face of the Crag, yet the disturbed beds associated with it are not easily seen. This rearing limestone is all that Hutton shows.

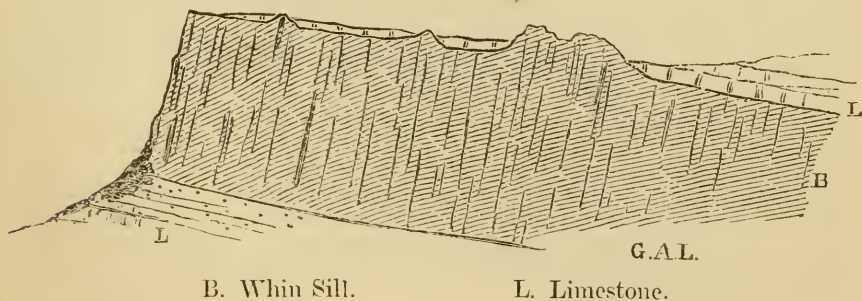
the escarpment of basalt, on the summit of which is built the Great Roman Wall, deserves special mention, first, as being an almost unique example of its kind, and, secondly, because, oddly enough, it has been (very inaccurately, it is true) figured by Hutton in the very paper in which he proved to his satisfaction the contemporaneity of the Whin.

A bed of limestone with an accompanying shale, which has for some distance from the west run regularly below the basalt and parallel to it, is here suddenly forced upwards almost vertically into the Whin, by which it is baked and altered in a very evident manner. Now where this limestone underlies the Whin Sill the latter is capped by sandstone; but immediately after the disturbance just described the limestone and shale are seen overlying the Whin in place of the sandstone, the outcrop of which, however, is in nowise disturbed by the occurrence, and can easily be traced running still parallel to but further above the trap-sheet.

This is merely a case of the Whin Sill being seen actually in the act (*flagrante delicto*) of shifting its horizon; but it has this further interest, that it proves that *at this point* the molten mass was forcing itself from east to west, the change having necessarily been from a lower to a higher horizon. This may have been but a local direction due to the mass having to circumvent obstacles in its progress, or to some other cause; but there are some reasons (*e.g.* the bifurcation to the N.E., the generally greater thickness in that direction, &c.) which would lead us to imagine that this is but a part of a general truth with regard to the position of the original focus of the Great-Whin eruption.

Although, as a rule, it may be said that the upper surface of the Whin is tolerably smooth, yet there are many instances of isolated masses, both great and small, having been thrust up from the main sheet to a greater or less distance through the overlying beds. The eastern branch, important as it is, must, we think, be looked upon as an extreme case of this kind; and between it and small bosses a few yards only in diameter, appearing as little islands through thin layers of limestone capping the Whin, of which there are very numerous examples on the dip-slope of Gunnerton Crag (fig. 5), at Great

Fig. 5.—Section at Gunnerton Crag, showing the upper surface of the main or western branch of the Whin Sill protruding through the overlying Limestone.



B. Whin Sill.

L. Limestone.

Bavington, at West Hills, and elsewhere, there is every gradation of size and form. It may be noted that although these "extra" outbursts, so to speak, are found occasionally in connexion with the main or western branch of the Whin, yet they are markedly more frequent to the dip of the eastern branch. In other words, *these tokens of ill-restrained energy are commonest where the ejecting force acted most vertically*. And they are moreover more common in the eastern than in the western portion of the Whin Sill's range, or where there was least pressure of overlying rock.

That notwithstanding its great thickness at its outcrop the Great Whin Sill should not have reached the denudation-line along its entire course, is perhaps somewhat surprising. But although in a few doubtful cases, which may be the result of faulting, the clear unbroken continuity of the beds above and below across the lines of the Whinless gaps can leave no doubt in the minds of field-observers that these breaks are distinct facts, that they are but surface breaks no one, we suppose, will dispute.

In its course through South-west and Mid Northumberland the Whin Sill runs more or less in the same direction as the larger faults. It is perhaps owing to this fact that the Whin is here seldom seen to be faulted. At the Stone-Croft lead-mine, near Haydon Bridge, the veins fault the Whin considerably. It is also faulted at Elf Hills, on the north of Hartington, at Wards Hill, and in many places to the north of Alnwick. We do not know of any perfectly clear case, although we have met with some doubtful ones, of the Whin being unaffected by a fault which throws the beds on both sides of it.

It may frequently be noticed that rocks adjacent to the Whin Sill are altered by it unequally. Sandstone is but little altered, shale very much so; limestone is sometimes but little changed, while at other times it is rendered crystalline. Recent experiments, in which one of us has taken part, have proved that shale is a very bad conductor of heat; limestone and sandstone are far better conductors*. We can therefore well understand how it is that shale should plainly show the effects of the Whin, when limestone and sandstone show but little alteration. It has been denied, by some who disbelieve in the intrusion of the Whin Sill, that alteration of the overlying beds has occurred. But of this there is abundant proof in the district which we have described†. The complete list of places where this may be observed is too long for insertion here; but we may mention the following as localities where the facts are particularly well shown:—Milking Gap, Sewing Shields, and Teppermoor on the line of the Roman Wall; West Hills and Three

* Prof. A. S. Herschel and G. A. Lebour, "On the Thermal Conductivities of certain Rocks," Rep. Brit. Assoc. for 1873 (Appendix), p. 223; for 1874, p. 128; for 1875, p. 54.

†. Prof. Sedgwick, fifty years back, gave most conclusive evidence of this in Teesdale; and the sections described by him may still be examined; but subsequent writers have mostly ignored, or endeavoured to explain away, his observations. (See especially pp. 162, 177, 178, and 182 of his second paper already referred to.)

Farms near Bavington; West Whelpington, Elf Hills, Shield Dykes, St. Margarets, Ratcheugh, and abundantly in the districts further north.

Fragments of altered rock are frequently found *in* the Whin. We cannot say whether these fragments belong to beds lying above or below; and therefore the fact of included sedimentary strata proves nothing. But the condition of the fragments is important evidence: they are pieces of shale or sandstone, not irregular amorphous masses such as would have occurred if the Whin had been poured over the ocean-floor and had caught up patches of newly deposited sediment in its progress. The shale immediately over the Whin, although greatly altered, is sometimes highly fossiliferous. This could not have been the case had the clayey sediment been laid down over freshly ejected lava.

The altered shale is frequently known as "Whetstone," a term also in use in Scotland for similar beds. When the shale can be used as slate-pencil it is known as "Cam;" Camboe, near Elf Hills, is by some supposed to derive its name from this circumstance.

Altered sandstone often greatly resembles altered or partly decomposed Whin. The surfaces of the Whin are frequently altered by the rocks it traverses quite as much as the rocks are altered by the Whin. This mutual metamorphism, or alteration, is even better shown by the Whin Dykes* than by the Whin Sill.

The Whin Sill frequently rises up in bosses of bare rock from a drift-covered country. Where there is no drift, or only a thin and partial covering, it generally forms the main feature of the immediate district in which it occurs. Its escarpment is not so lofty as that of the thick sandstones, which chiefly lie on lower horizons; but it is usually more bold and precipitous in proportion to its height. The Whin Sill can frequently be distinguished at a distance by the character of the vegetation. Mr. Tate states that the following plants occur in Northumberland only on the basalt—*Mœnchia erecta*, *Sagina subulata*, *Vicia lathyroides*, *Asperugo procumbens*, *Statice limonium*, *Convallaria polygonatum*, *Allium schoenoprasum*, *Scilla verna*, *Sedum anglicum*, *Asplenium septentrionale*, and *A. germanicum*. *Helianthemum vulgare*, although also occurring on the limestone, is very characteristic of the Whin Sill†.

5. *Mineral Characters of the Whin Sill.*—Into this subject we need not enter, inasmuch as Mr. Allport has quite recently done so at length before this Society. Of the specimens described by him‡ two were from our district. That from Ward's Hill is a good typical example of the Whin Sill generally. That from Elf Hills was from one of the small strings of trap shown in fig. 2 (p. 413). It is by no means a fair example of the trap, being excessively fine in grain, almost resembling a hardened clay; it is moreover much decomposed.

* It may be well to mention that faults in the N. of England are called "dykes" or "troubles." Basaltic dykes are specially distinguished as "Whin dykes" or "Whin troubles."

† New Flora of Northumberland and Durham, p. 35, 1868.

‡ Quart. Journ. Geol. Soc. vol. xxx. p. 552, 1874.

As a rule, we find that the thicker the Whin the coarser the grain of the rock. This is perhaps due to the slower cooling of the thick masses allowing crystallization to develop more perfectly.

The Whin Sill is not often vesicular, and still more rarely amygdaloidal. When it is, it is not more so near the upper surface than elsewhere; nor is it more so than some of the Whin Dykes which traverse the country. No volcanic ash occurs in the district; nor is there any spot which can be pointed out as certainly a vent or neck, up which the trap came.

6. *Age and Origin.*—The foregoing statements have proved that the Whin Sill is newer than the beds of the Carboniferous-Limestone Series in which it lies. But the question of the exact age of the intrusive sheets yet remains to be determined. So far as Northumberland is concerned, the question must remain an open one.

The Whin Sill is older than most of the faults of the district in which it occurs, because these throw trap and sedimentary beds alike. As already mentioned, we have no clear case of the Whin being unaffected by (or later than) any of the faults. The Whin is also clearly older than the mineral lodes of the district. But what the age of faults and lodes may be we do not know. Some of the faults are probably pre-Permian; at least the Magnesian Limestone appears to be unaffected by certain faults which are proved in Coal-workings beneath*. Others, and these generally the large east-and-west faults, are clearly post-Permian. But we cannot generalize as to the age of the faults in this district merely by their direction; and even if we could, the known instances of faults in the Whin Sill are not sufficiently numerous to allow us to apply the test with safety.

In Scotland, Warwickshire, and Staffordshire there are intrusive sheets of trap in the Coal Measures, but none in the adjacent Permians. Negative evidence in these cases strongly suggests that the trap is pre-Permian; and the conclusion thus suggested is generally adopted. Without wishing to call this conclusion in question, we should like to make a few remarks upon this kind of evidence.

If the Permians can be shown to have been deposited upon the *denuded edges of the trap*, the proof is complete. But it is only very rarely that such proof can be given. Generally, the evidence is of this nature:—Carboniferous rocks, in which intrusive sheets of trap now occur, have been disturbed and denuded, and their edges covered up by unconformable Permians. This, however, is not sufficient proof; or rather it is no proof at all; for the trap may have been intruded into the Carboniferous rocks long after the deposition of the Permians. There is evidently a tendency for these sheets of trap to keep along the lines of bedding; otherwise there would never be any doubt as to their character. If the intruding trap began to force its way laterally first through the Carboniferous rocks, it would probably, if possible, stay there. A difficulty here occurs

* See Sheet 105 S.E. of the Geological-Survey Map, and the 6-inch Map of the Durham Coal-field; surveyed by Mr. Howell.

if the rocks have been much disturbed and faulted before the deposition of the Permians. In this case the tendency to keep along the lines of bedding, would doubtless be greatly lessened.

The question turns upon the amount of negative evidence. If we find intruded sheets of trap in Carboniferous rocks in the neighbourhood of unconformable Permians, and never find the trap entering the latter, there is presumptive evidence in favour of the view that the trap is pre-Permian. But this is only negative evidence at best, and, however much there may be of it, it can never amount to proof; nor can it be allowed any weight as against a single fact on the other side.

But in Staffordshire and Ayrshire we are not dependent only on such negative evidence; there many faults which throw Coal Measures and trap alike, do not throw the Permians. In these cases the evidence is positive, and of great force. It gives the age of the trap with sufficient clearness: the trap is newer than the Coal Measures in which it lies; it is older than the faults which throw it; and these faults are older than the Permians *of those areas*.

The Whin Sill of the Penine escarpment approaches to within a mile or two of the Permians of the Vale of Eden; and here an interesting question arises. The Carboniferous rocks are well developed on the west of the Penine fault; but Mr. Goodchild informs us that in no case, so far as is yet known, do they contain any beds of trap, although the beds in which Whin Sill might be expected to occur are there seen. Two explanations of this are possible. It may be because the beds to the west of the escarpment were faulted down to the west before the intrusion of the Whin Sill, and the westerly continuation of the Sill, in beds newer than the Carboniferous, has been removed by denudation: in this case the Whin Sill would be post-Permian.

Another explanation is this:—The Whin may have been injected before the faulting of the beds, but, because of its thinning to the west, it did not reach so far as the Carboniferous beds which lie on the west of the Vale of Eden.

The latter is the more probable explanation; or at least it is the one which may most safely be suggested. The westerly thinning of the Whin Sill, from Teesdale to the Penine escarpment, is a fact which is well proved. The thinning of the Sill to the west is seen in the small transverse valley at High-Cup Nick. The same occurs with the “Little Whin Sill,” of Weardale. This is 20 feet or more thick on the east, but it wedges out entirely about 3 miles to the west.

As there are no “necks” on the west of the line of outcrop of the Whin which can have served to give vent to the trap, we must conclude that it came up in some area to the east of its present outcrop. The westerly thinning of the Whin in certain districts also points to the same conclusion.

We have, then, no good evidence in our district as to the age of the Whin Sill; but by comparison with other districts it appears safer to regard it for the present as probably of late Carboniferous,

or possibly of early Permian age*. Prof. Sedgwick believed that the Whin Sill had been injected before the deposition of the Magnesian Limestone. Mr. Tate, chiefly from his interpretation of the evidence of faults and lodes, regarded it as "subsequent to the Carboniferous, and prior to the Triassic era."

In this view of the case, it is important to consider the amount of consolidation which the beds had undergone, and the thickness of beds deposited previous to the intrusion of the Whin. The Carboniferous rocks of other districts seem often to have been generally more altered and disturbed by the intruding trap than do those of our area; they seem to have been less fully consolidated, and to have presented less resistance to the eruption of the trap.

So far as we can judge, the rocks of our area had been fairly well consolidated (the clayey sediment had been compressed into shale, and the carbonaceous matter had been fully changed into coal) before the injection of the trap. There must have been a very great thickness of rock overlying the Limestone Series at that time; else we should find, far more often than we do, that the Whin has broken completely through the beds.

The Coal Measures of the Newcastle Coal-field have a thickness of about 1800 or 2000 feet, the highest English Coal-measures not being now represented in this district†. The Whin Sill, where at its highest position in Mid Northumberland, lies below the base of the Coal Measures, from 2000 to 3000 feet, according to the development of the intervening beds. Therefore, if the intrusion took place during the higher Coal-measure period, there would have been a total thickness of from 3500 to 5000 feet of rock overlying the Whin.

It may be a question whether the time which elapsed between the deposition of the beds now found with the Whin, and the pressure of some 5000 feet of superincumbent rock, would have been sufficient to alter the lower beds from original sediment into sandstone, shale, limestone, and coal. If this be admitted, there is still the question whether the pressure would have been sufficient to keep the intruding sheet of lava between the lines of bedding.

It is a fact of some moment, that when the Whin lies high in the series it seems most prone to break through the rocks; but there are many exceptions to this.

If the intrusion took place when the whole country was deeply covered by Secondary rocks, it is not likely that the pressure of from 1000 to 1500 feet of strata, more or less, would make any perceptible difference. But if the intrusion took place during the higher Coal-measure period, when the thickness of overlying rock

* We do not here enter into the question of the relations of the Permian and Carboniferous. In Northumberland and Durham the higher Coal Measures are not present, and the Magnesian Limestone, with the underlying Yellow Sand and Marl Slate, clearly lie unconformably upon such Coal Measures as there occur. Stratigraphically the break is there complete.

† The highest Coal Measures of Northumberland are those just on the north or downthrow side of the famous "90-fathom dyke," near Gosforth and Killingworth. The dyke, or fault, has here a throw of 200 fathoms.

varied from 3500 to 6000 feet, the difference would probably be very important.

The relation which the Whin Dykes of the district bear to the Whin Sill is an interesting question; but it is one upon which little can be said. There is no certain case in Northumberland of a Whin dyke intersecting the Whin Sill; but to the south of Alnwick, near Shield Dykes, there is an instance which strongly suggests this.

The Whin Dykes are generally dykes and nothing more. In only a few cases have they been proved to send out lateral branches amongst the strata. A brief enumeration of some localities in which this has been observed is given by Mr. I. L. Bell in a paper on the chemical alteration of Whin at and near its contact with sedimentary rocks*.

The Whin Dyke which runs from near the coast, past Radcliffe Colliery, Acklington and Cartington, into the Porphyrite of the Cheviots, seems to overflow at Clennel, just before entering the Cheviot country. There are some curious beds of Whin in a shaft at Shilbottle Colliery, south-east of Alnwick; Mr. Tate supposed them to be overflows from a Whin dyke which occurs close by; but whether this is so, or whether they belong to the Whin Sill, cannot at present be proved.

7. *Conclusion.*—The foregoing paper has touched upon several collateral subjects; but the main point has been to establish the intrusive character of the Whin Sill. That this has been injected between the strata, after their deposition and consolidation, is, we think, now sufficiently evident.

The exact geological date at which the intrusion took place cannot be determined. Northumberland offers no conclusive evidence upon the subject; but so far as the evidence in this and other districts goes, it seems probable that the intrusion took place at the close of the Carboniferous period.

Of the relations of the Whin Dykes of Northumberland to the Whin Sill we have no certain knowledge. The dykes may be of different ages; and some of them probably belong to the same period as the majority of the long trap dykes of the south of Scotland, which Prof. A. Geikie has shown to be of Tertiary age.

EXPLANATION OF PLATE XVIII.

Sections of the Carboniferous-Limestone series of Northumberland, showing the positions of the Whin Sill.

DISCUSSION.

Mr. WARINGTON W. SMYTH said that he had gone over the district referred to in the paper with Mr. Blackwell, the geologist who first determined the intrusive character of the green-and-white rock

* Proc. Roy. Soc., vol. xxiii. p. 543, 1875. See also a notice by Mr. A. L. Stevenson, Trans. N. of Engl. Inst. Eng. vol. xxiii. p. 160, 1874. Mr. Bell refers to the Whin Sill as a "bedded trap;" but probably he does not attach to that term the idea of contemporaneity.

in the neighbourhood of Dudley. Mr. Blackwell was also, he believed, among the first to suggest the intrusive nature of the Whin Sill of Northumberland. It appeared to be a great intruded tongue, not quite horizontal, but approximately so; and it was interesting to see the evidence brought forward by the authors proving its occurrence at various horizons.

Prof. HUGHES thought that the intrusive character of the Whin Sill was proved in the sections seen in Hicup Gill and elsewhere along the same escarpment, as the rocks were altered above and below it, and were seen to be traversed obliquely by it in such a manner as could not be explained simply by the thinning out of the sedimentary deposits.

He thought that the Brockram and other New-Red deposits of the Eden valley were the shore deposits of the sea further out, in which sooner or later the Magnesian Limestone of the district west of the Pennine range was formed; that, whatever may have happened in earlier times, there was certainly a great faulting after the deposition of the Lower New Red, so that the cliff, with the Whin Sill exposed in it, did not exist there when the conglomerates known as Brockram were formed; that the beds into which the Whin is intruded do not occur on the S.W. of the Brockram, though it may be that beds of the same age, but very different in character, may occur further north beyond the main mass of Brockram; that the Brockram now exposed was derived chiefly from Mountain Limestone further west, so that the absence of Whin in it goes for nothing; that there is no evidence to show whether or not the Whin has an outcrop under the New Red or runs into it; and on the whole, except we identify it with the dykes which run across the Jurassic rocks to the east, there is nothing proved in that district respecting its age except that it must be later than the Lower Carboniferous.

Mr. LEBOUR said that Prof. Hughes was right with regard to the absence of the Whin Sill in the southern extension of the western Yoredale rocks. The alteration produced by the Whin Sill differed according to the kind of rock affected by it; and the difference was probably due to the different conductivity for heat of the various rocks.

